The PRISM project

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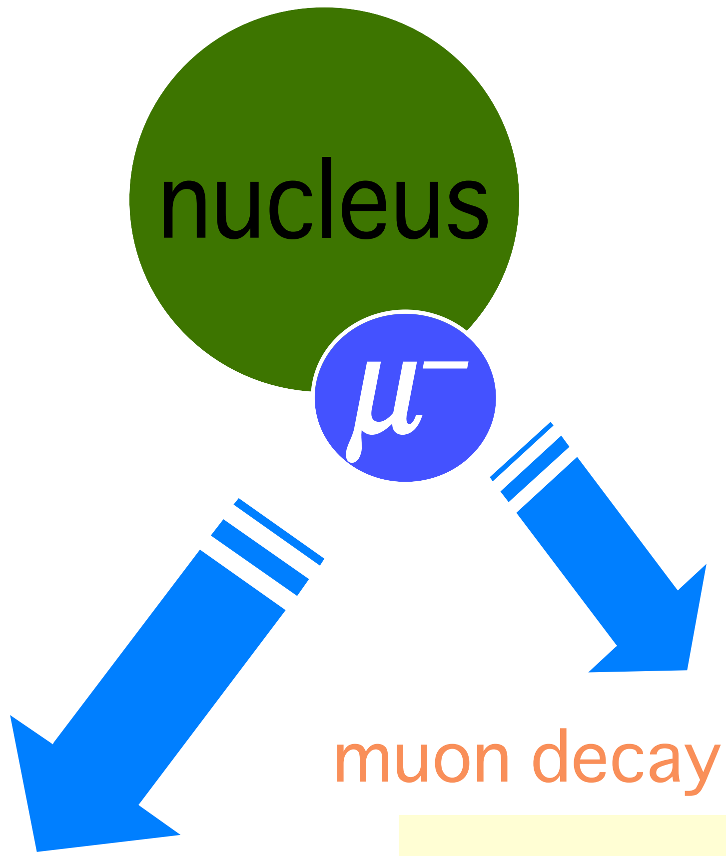
Outline

- Limits for the COMET and Mu2e experiment
  - signal sensitivity
  - high-Z stopping material
- PRISM concept
- R&Ds
- PRISM Task Force
- Summary

Muon - Electron Conversion

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

Neutrino-less muon nuclear capture (=μ-e conversion)

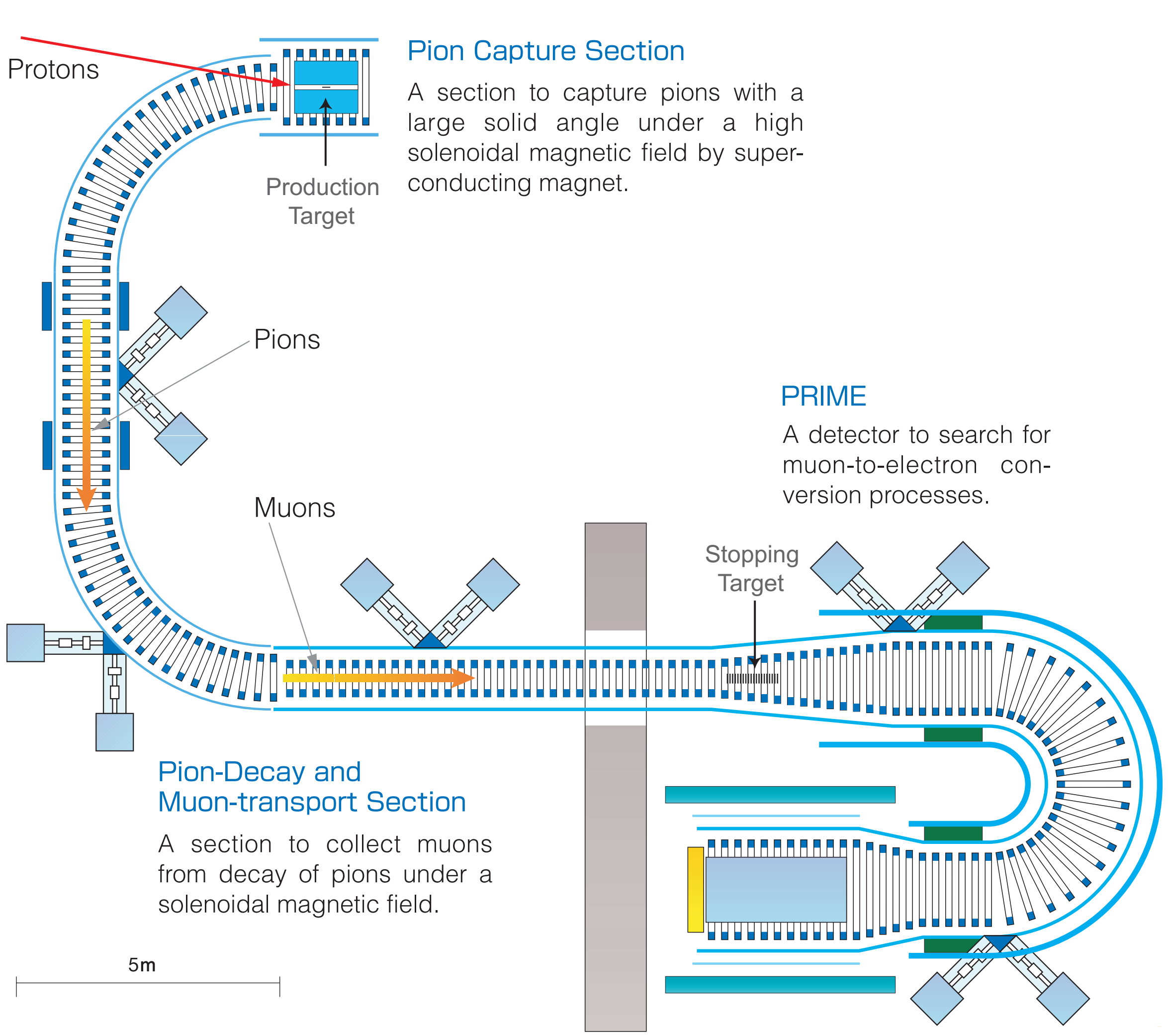
$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

signal :

$$m_\mu - B_\mu \sim 105 MeV$$

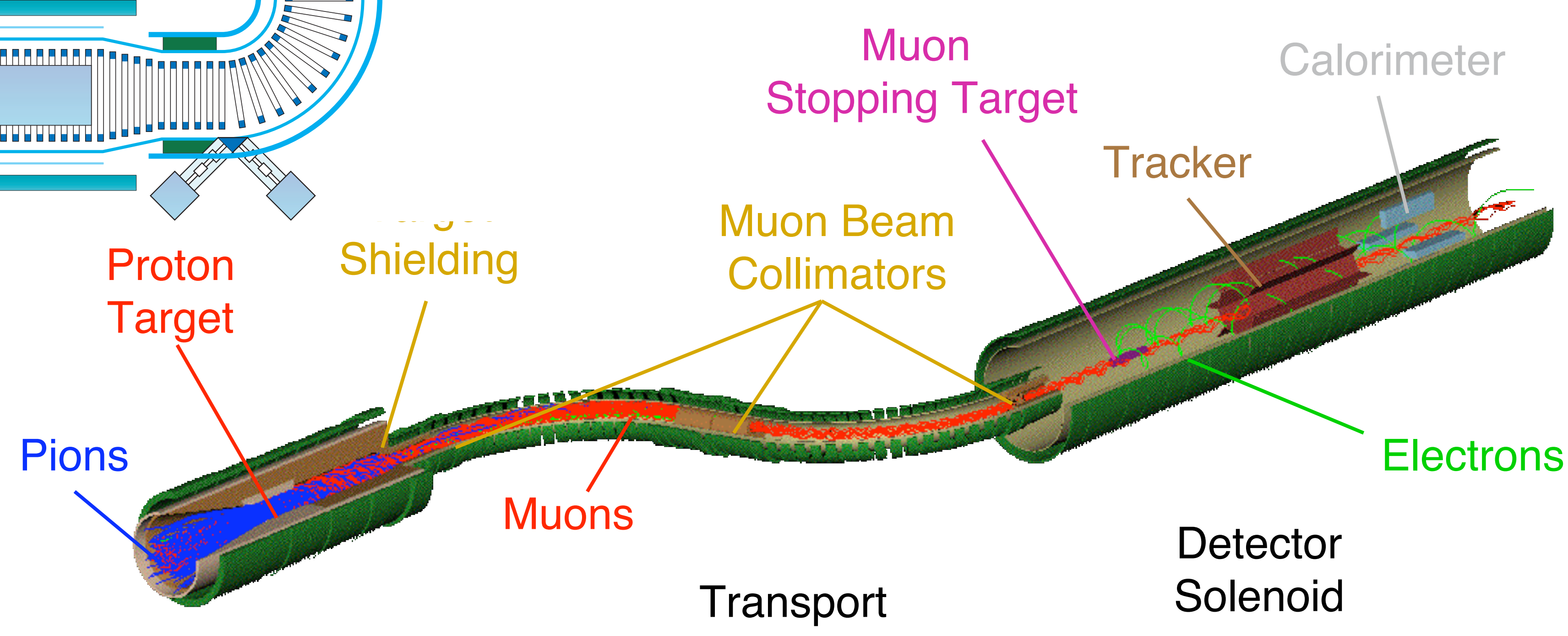
$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

COMET and Mu2e(MECO-type):



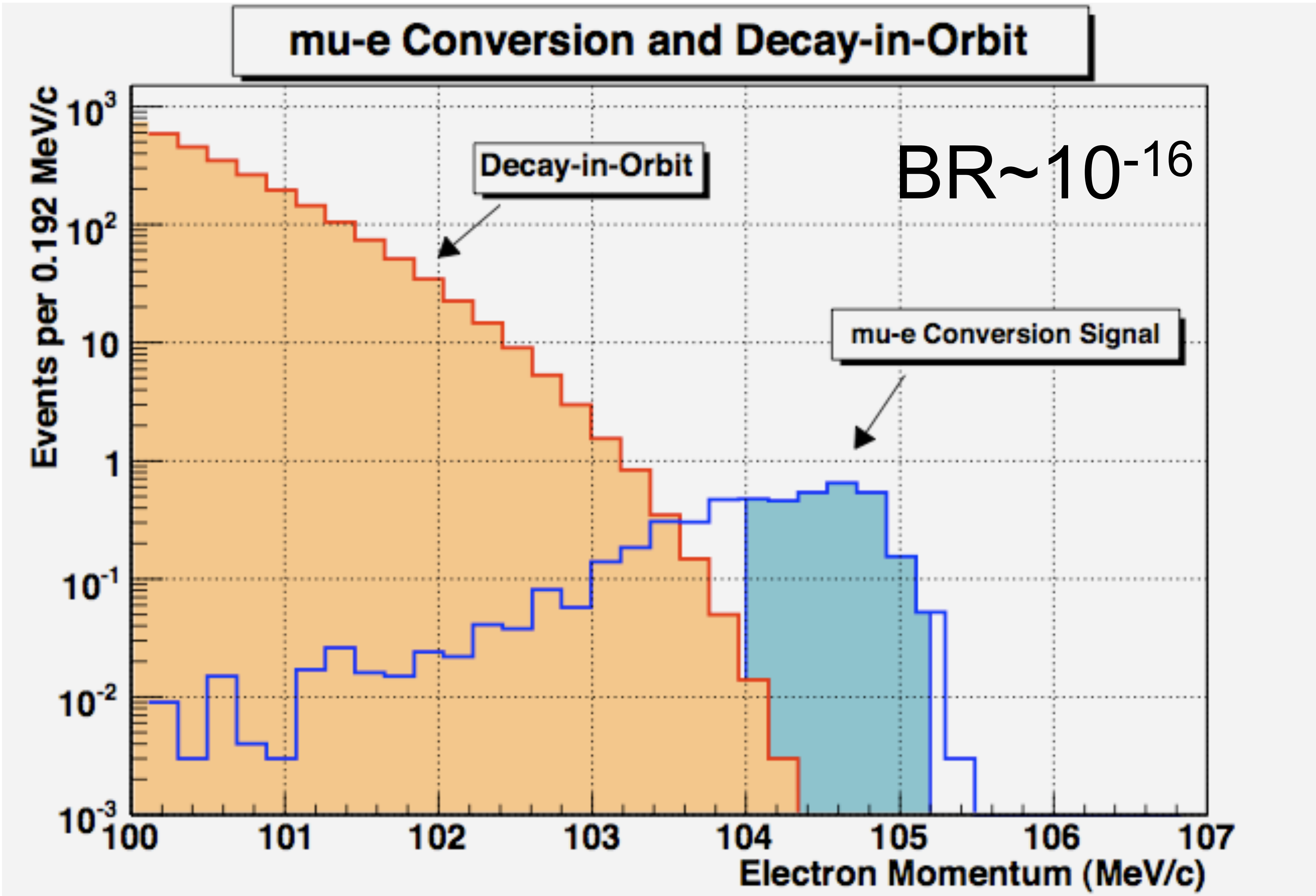
$$B(\mu^- + Al \rightarrow e^- + Al) < 10^{-16}$$

- Solenoid channel
- Stop μ^- at the stopping targets.
- ID single electron from the target and measure its energy precisely.
- Suppress backgrounds strongly.



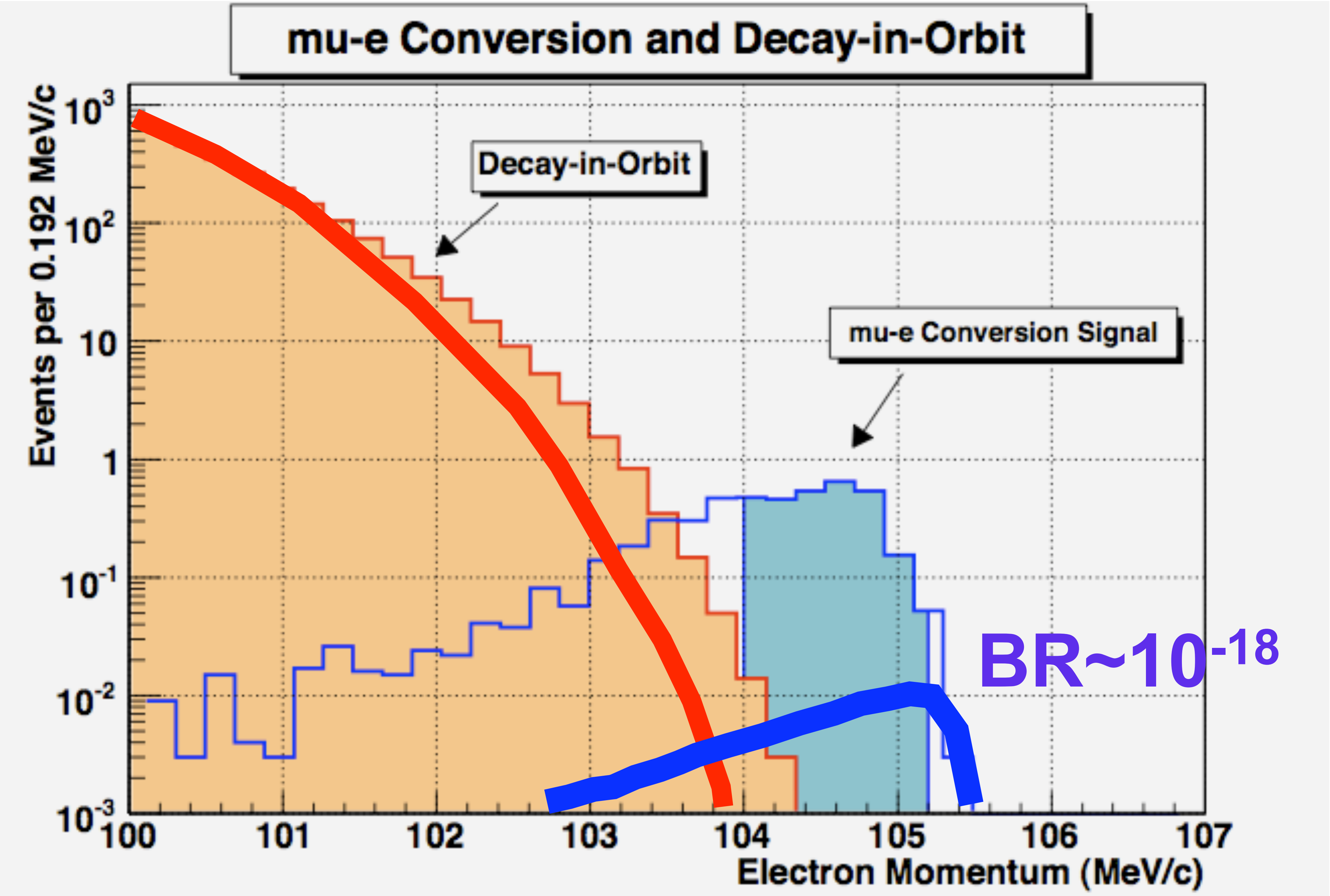
The MECO type experiments have some limitation on achievable sensitivity and physics studies.

Decay-in-Orbit Background



- To distinguish the signals from the DIO backgrounds, electron energy must be reconstructed with sufficient resolution. The present resolution is dominated by the energy struggling in the stopping target.

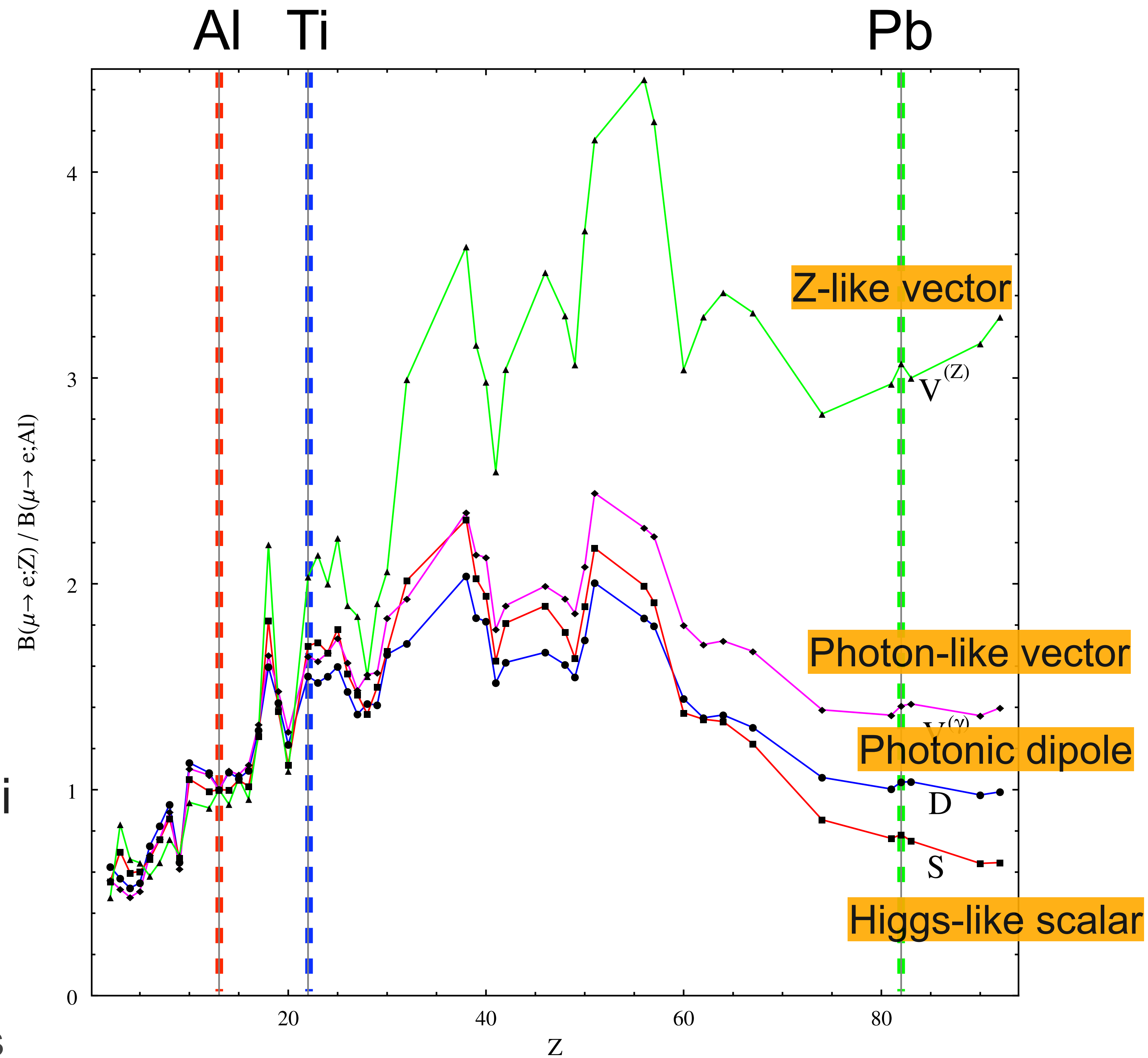
Decay-in-Orbit Background (cont.)



- To achieve a signal sensitivity < 10^{-18}, we need improve the energy resolution.
- Thinner stopping targets with a sufficient muon stopping efficiency is necessary. --> **Mono-energetic muon beam is useful!**

Target dependence of μ-e conversion

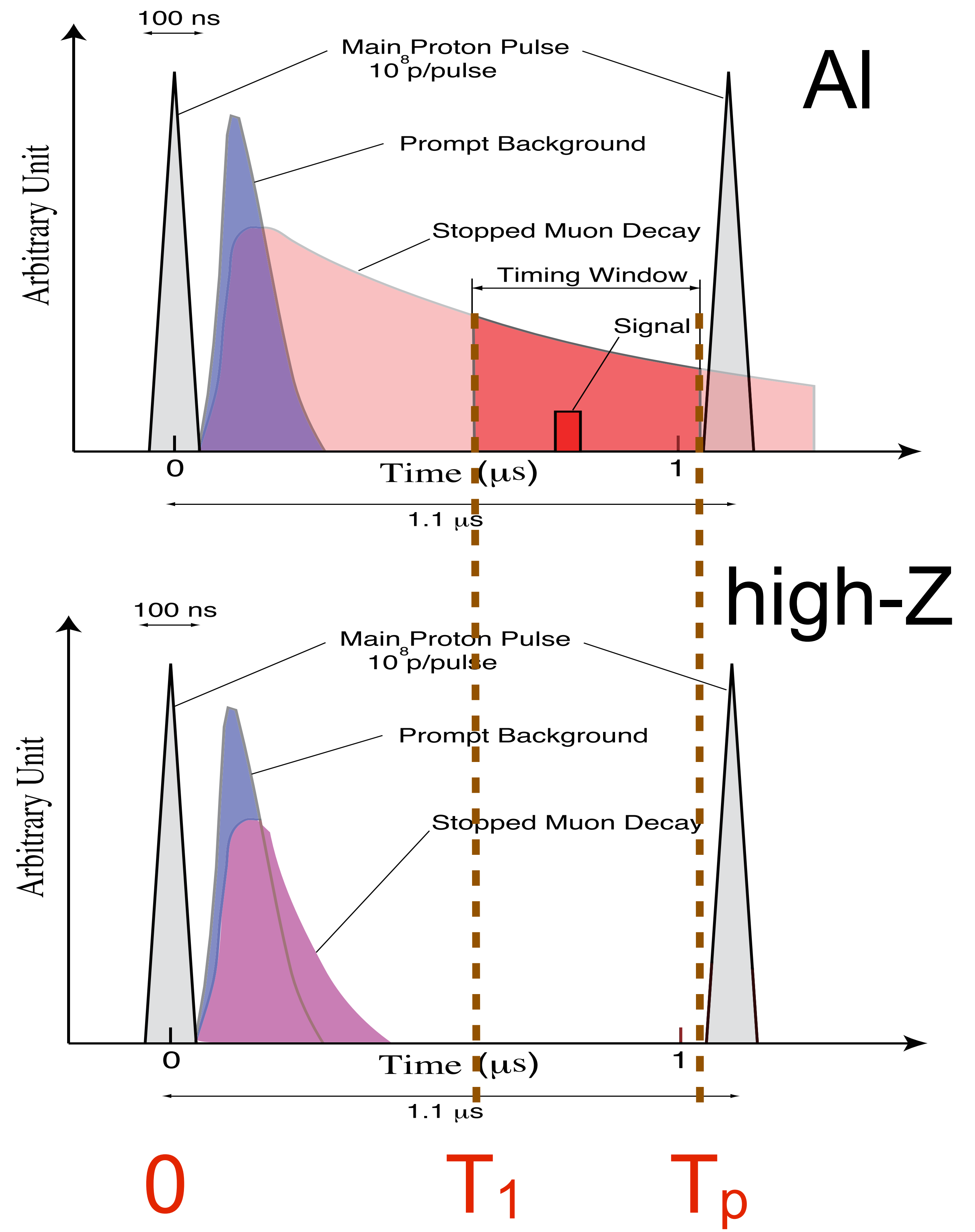
- Once a signal of the μ-e conversion is observed, one can obtain information on models of the new physics, by changing the target material, even if μ→eγ is not observed.
- Contribution of different type of LFV operators is different from each nuclei.
  - Maximal in the intermediate nuclei
  - Significantly Different Z dependence for heavy nuclei
- BUT, higher Z target makes shorter μ lifetime in a muonic atom.
  - Al : 880ns, Ti : 329ns, Pb : 82ns



V.Cirigliano et al, Phys. Rev. D 80 013002 (2009)

Time distribution of backgrounds and signal

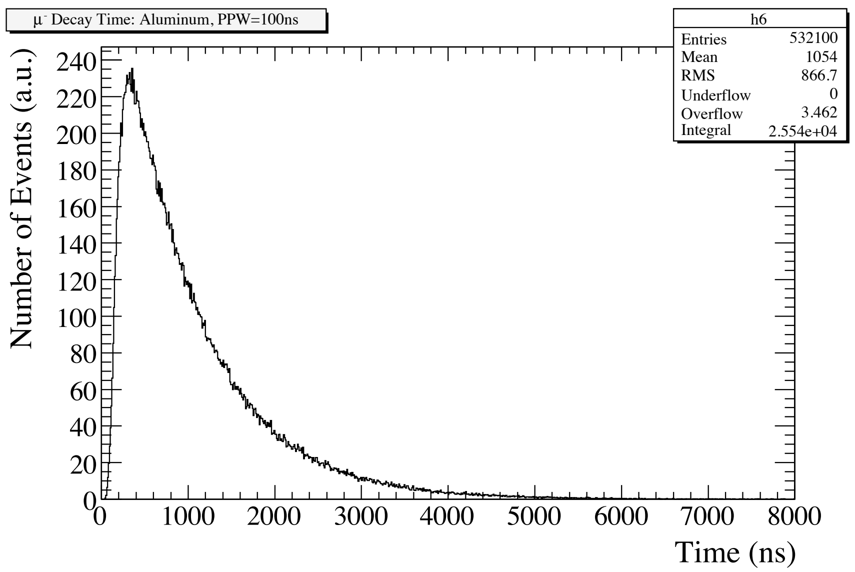
- The muons stopped in the muon-stopping target have the lifetime of a muonic atom. The time distribution of muon decays with the distribution of muon arrival timing is shown in Figure.
- Huge prompt BG exists just after the prompt timing. BUT Some beam-related backgrounds would come even after the prompt timing. Therefore, the measurement time window is selected to start after the prompt timing.
- The time window acceptance depends on the muon lifetime.

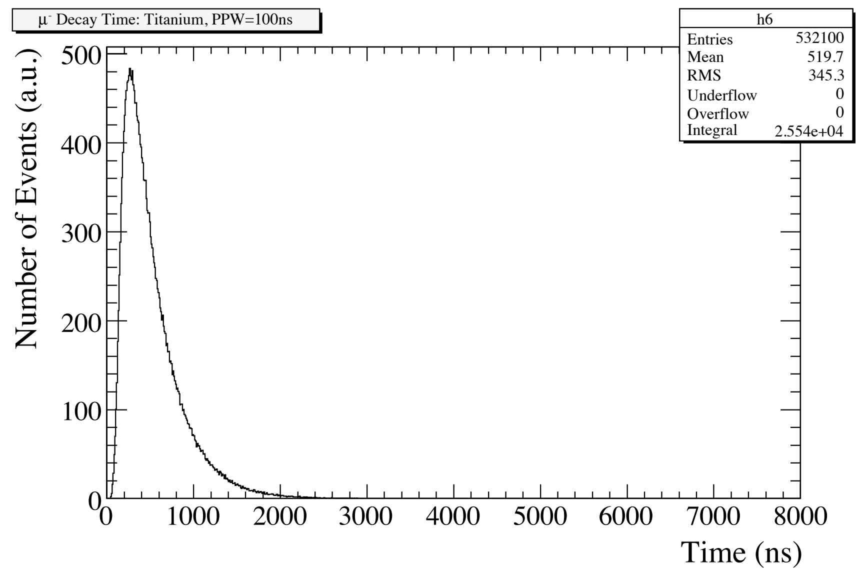


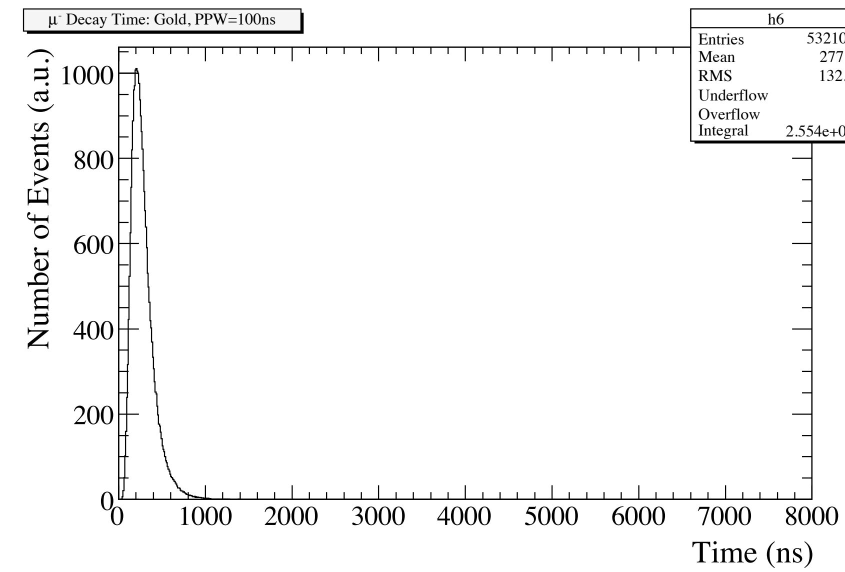
Timing window selection efficiencies for COMET

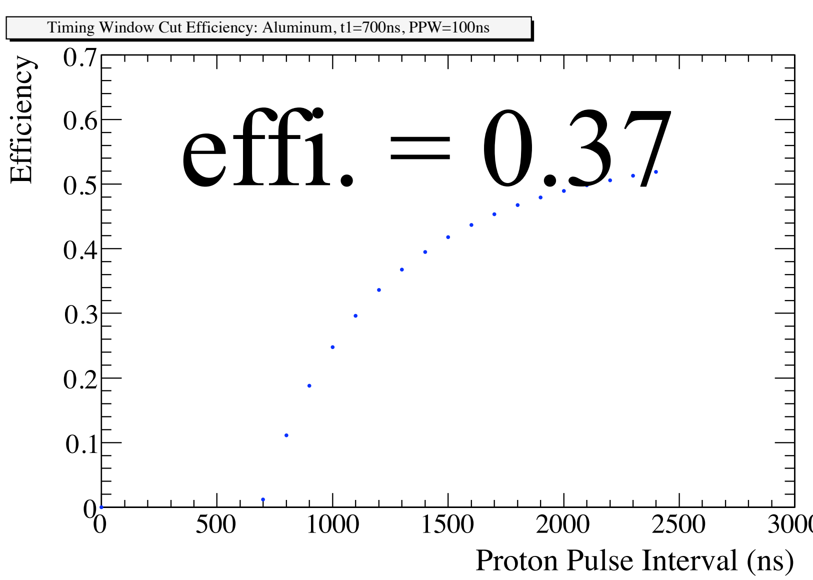
t_1=700ns, T_p=1314ns

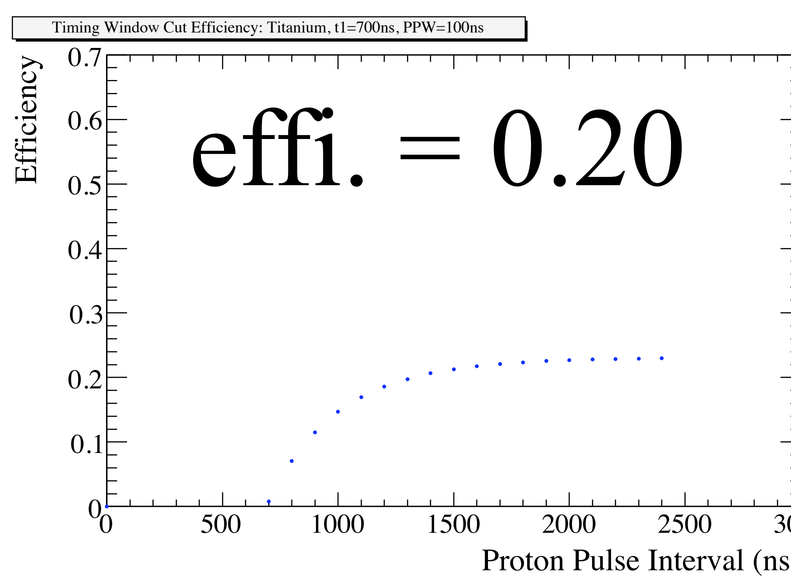
Al (τ=864ns) Ti (τ=330ns) Au (τ=88ns)

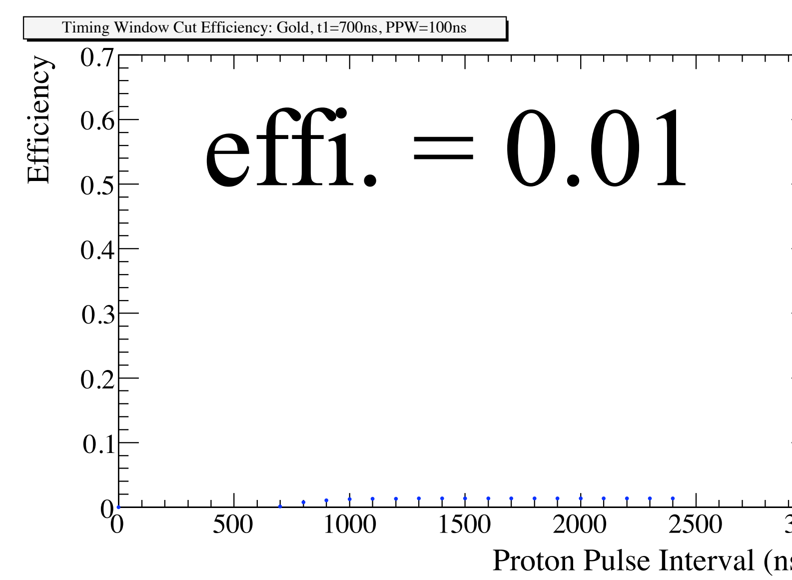












To measure BR with a high-Z target, the beam related backgrounds (pion radiative decay, beam flash etc) must be highly suppressed.

Summary of limits for the MECO type experiments

- A signal sensitivity < 10^{-17} would be impossible with the MECO-type experiments.
  - large flux of prompt backgrounds. ex. pion radiative decay etc
  - thick stopping target makes insufficient electron energy resolution.
- Measurement efficiency with high-Z stopping target would be poor.

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A mono-energetic and pure muon beam can solve these issues.

The next generation μ-e conversion experiment with PRISM!

Further Background Rejection to < 10^{-18}

mono-energetic muon beam

Muon DIO & Beam flush → narrow muon beam spread — 1/10 thickness muon stopping target

pure muon beam

Pion background → long muon beam-line — muon storage ring

Beam-related Background → Extinction at muon beam — fast kickers

Cosmic-ray background → low-duty running — 100 Hz rather than 1 MHz

PRISM : Phase Rotated Intense Slow Muon source

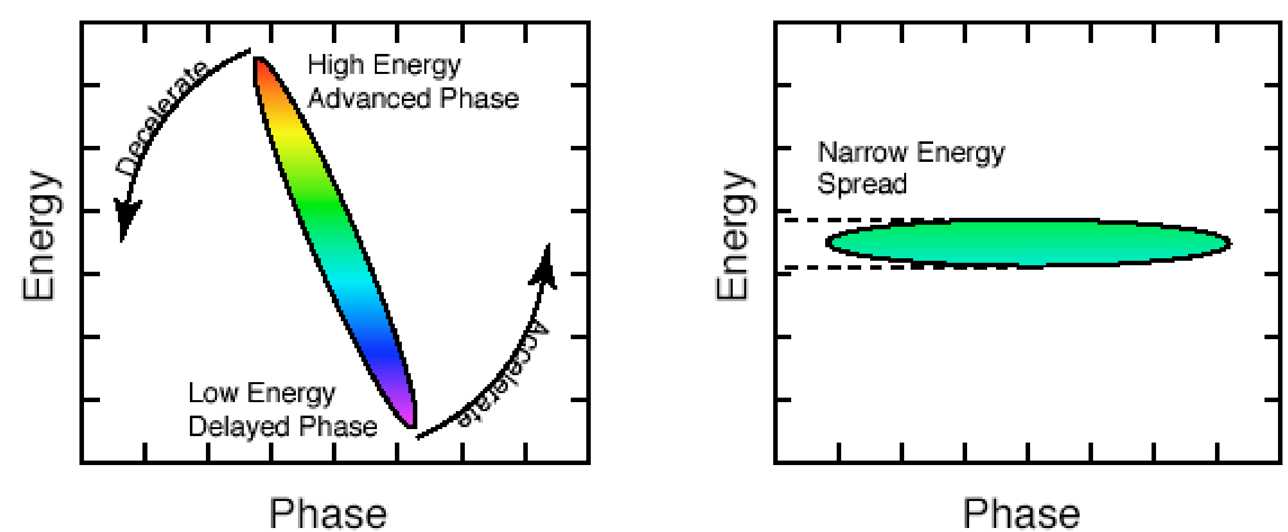
- **High intensity**
  - intensity : 10^{11}-$10^{12}\mu^{\pm}$/sec
  - beam repetition :100-1000Hz
  - kinetic energy : 20MeV(=68MeV/c)
- **Narrow energy spread**
  - kinetic energy spread : ±0.5-1.0MeV
- **Less beam contamination**
  - contamination < 10^{-18}

PRIME : PRIsm Muon to Electron Conv. Experiment

sensitivity of $\mu \rightarrow e \sim 10^{-18}$

To Make Narrow Beam Energy Spread

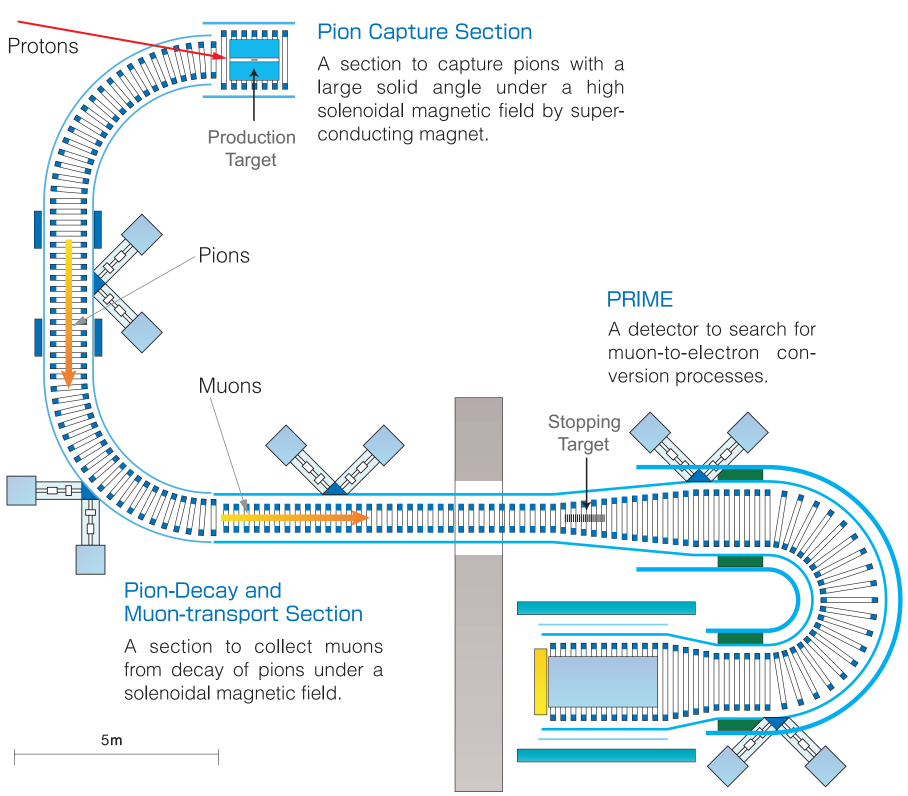
- A technique of phase rotation is adopted.
- The phase rotation is to decelerate fast beam particles and accelerate slow beam particles.
- To identify energy of beam particles, a time of flight (TOF) from the proton bunch is used.
- Fast particle comes earlier and slow particle comes late.
- Proton beam pulse should be narrow (< 10 nsec).
- Phase rotation is a well-established technique, but how to apply a tertiary beam like muons (broad emittance) ?



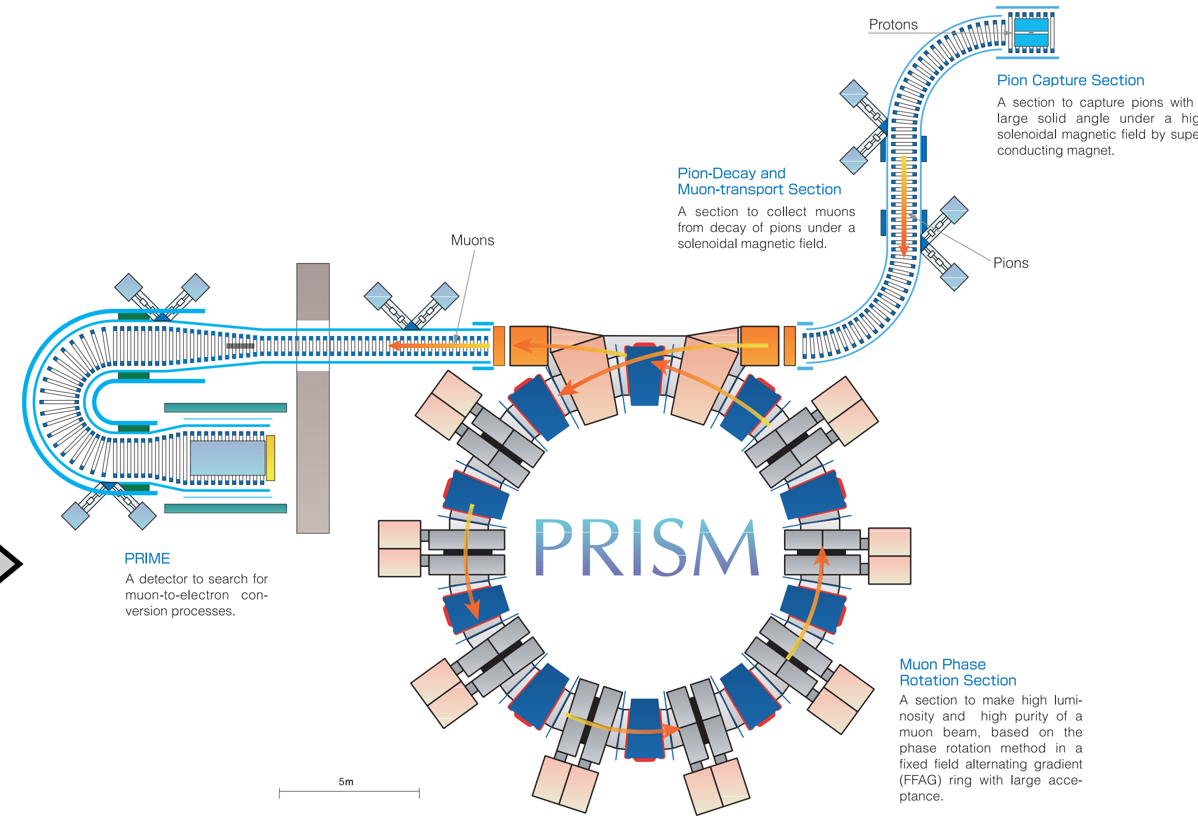
Japanese staging plan of mu-e conversion

PRISM

1st Stage : COMET



2nd Stage : PRISM/PRIME



$$B(\mu^- + Al \to e^- + Al) < 10^{-16}$$

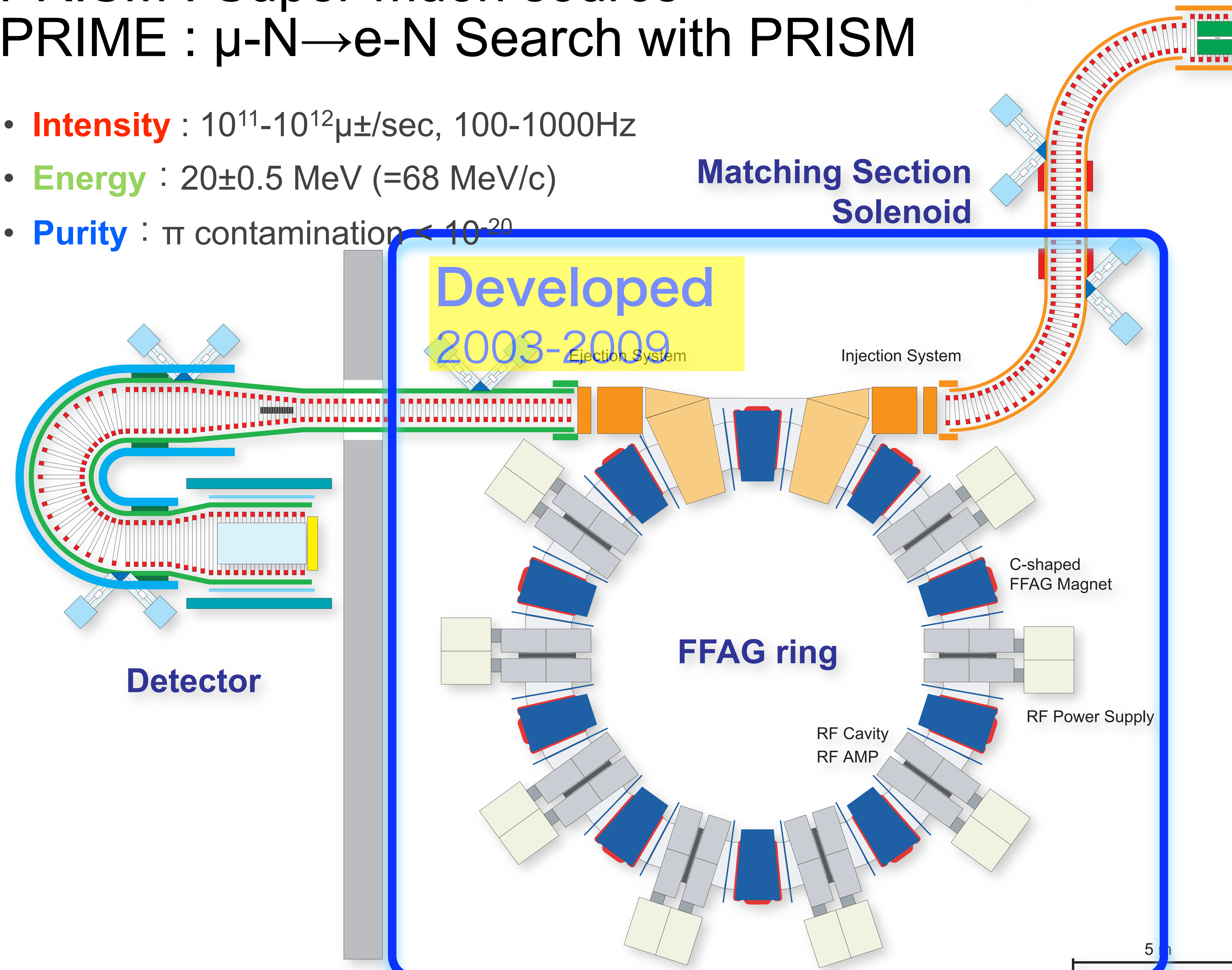
- without a muon storage ring.
- with a slowly-extracted pulsed proton beam.
- doable at the J-PARC NP Hall.
- regarded as the first phase / MECO type
- Early realization

$$B(\mu^- + Ti \to e^- + Ti) < 10^{-18}$$

- with a muon storage ring.
- with a fast-extracted pulsed proton beam.
- need a new beamline and experimental hall.
- regarded as the second phase.
- Ultimate search

PRISM : Super-muon source
PRIME : μ-N→e-N Search with PRISM

- **Intensity** : 10^{11}-10^{12}μ±/sec, 100-1000Hz
- **Energy** : 20±0.5 MeV (=68 MeV/c)
- **Purity** : π contamination < 10^{-20}



PRISM-FFAG

PRISM

- **Functions**
  - makes monoenergetic muons : **phase rotation**
  - reduces π in the beam : **long flight length**
- **Requirements & R&D items**
  - **Large acceptance FFAG-ring**
    - Horizontal : 38000 π mm mrad
    - Vertical : 5700 π mm mrad
    - Momentum : 68MeV/c +- 20%
  - **High field grad. RF system (170kV/m = 2MV/turn)**
    - Quick phase rotation
      - ~1.5μs

6-sector PRISM-FFAG at RCNP, Osaka Univ.

PRISM Task Force

- The PRISM-FFAG Task Force was proposed and discussed during the last PRISM-FFAG workshop at IC (1-2 July'09).
- The aim of the PRISM-FFAG Task Force is to address the technological challenges in realizing an FFAG based muon-to-electron conversion experiment, but also to strengthen the R&D for muon accelerators in the context of the Neutrino Factory and future muon physics experiments.
- It was proposed to achieve a conceptual design of the PRISM machine at the end of 2010/beginning 2011.
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PRISM Task Force (cont.)

- The following key areas of activity were identified and proposed to be covered within the Task Force:
  - \- the physics of muon to electron conversion,
    \- proton source,
    \- pion capture,
    \- muon beam transport,
    \- injection and extraction for PRISM-FFAG ring,
    \- FFAG ring design including the search for a new improved version,
    \- FFAG hardware R&D for RF system and injection/extraction kicker and septum magnets.

- Please join! j.pasternak@imperial.ac.uk

Summary

- COMET and Mu2e has the limitation on the achievable sensitivity (can not go < 10^{-17}) and usage of high-Z material as a stopping target to study the nature of the new physics.
- To solve these issues, we need to modify and/or add some devices to the MECO type setup. PRISM/PRIME is a solution using a muon storage ring. LOI submitted to J-PARC. But needs more R&Ds.
- Project X could be nice proton driver for PRISM/PRIME type experiments to get BR<10^{-18}. Needs studies and discussions.
- The PRISM-Task Force was established to make realistic design of a PRISM based μ-e conversion experiment as an ultimate experiment. Your collaboration is welcomed!